EXPERIMENTAL ANALYSIS OF KEY PARAMETERS OF LASER ION WELDING OF HONEYCOMB PLATE HEAT EXCHANGER

by

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The combination of laser deep penetration welding and hydraulic bulging is the most advanced production technology of honeycomb plate heat exchanger in the world. The micro-shape and heat transfer effect of the heat exchanger of honeycomb plate are mainly determined by the distribution mode of welding spot, weld shape and welding point arrangement. Therefore, the important principle of the honeycomb plate heat exchanger processing is to improve the pressure as much as possible to form turbulence while ensuring the welding quality. In the present experimental work, the effect of different weld shape and weld distribution of honeycomb plate heat exchanger produced by 06cr19n10 plate using hydraulic bulging and laser deep penetration welding on hydraulic bulging effect was studied carefully. The results showed that the optimal arrangement method is the equilateral triangle. The welding process parameters were optimized to increase the welding strength. The results showed that when the welding power was 2.1 kW, the bonding strength of the weld was the highest, at 52.70 kN. When the welding power was 2.2 kW and the gap between the welding points was 30 mm, the tensile strength of the honeycomb plate was the best, at 19.0 MPa. The results of this paper provide experimental support for industrial production of honeycomb plate heat exchanger.

Key words*: laser deep penetration welding, honeycomb plate heat exchanger, process parameters, hydraulic bulging, experimental analysis*

Introduction

The honeycomb plate heat exchanger belongs to the plate heat exchanger. It has many advantages such as high heat transfer efficiency, small footprint, convenient installation, lightweight, and low fouling coefficient. In today's society, which emphasizes the efficiency of energy use, this type of heat exchanger film is becoming more and more attention. At present, the honeycomb plate heat exchanger has been widely used in the fields of chemistry, refrigeration, metallurgy and HVAC [1-4]. According to its structure, the honeycomb plate heat exchanger belongs to semi-welded plate heat exchangers. To be specific, the honeycomb plate heat exchanger consists of two pieces of plate, which are welded to form a plate pair. The network-like contacts are formed between the adjacent plates and are supported by each other, so the plate stiffness is obviously enhanced. A cavity is formed between plates to form a medium channel. The plate pair and the plate pair are sealed with non-metallic gaskets and form another medium channel. When the honeycomb plate heat exchanger is working, the two kinds of fluid medium flow evenly in the adjacent channel, thus complete the full heat exchange process. Therefore,

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the flow state and heat transfer coefficient of the fluid is an important factor to determine the thermal efficiency.

In order to increase the heat transfer efficiency of honeycomb plate heat exchanger, Liu designed a new type of honeycomb radiator cooling system, then carried out experimental research under different flow and input heating power [5]. Wang *et al.* [6] uses genetic algorithms to optimize the honeycomb plate heat exchanger. Murre *et al.* [7] proposed a thermal model to describe heat transfer in porous rectangular plates. In addition, many researchers have conducted research on honeycomb heat exchangers [8-15]. However, most of these tasks are simulated by using the finite element method to heat the process or the movement of the fluid. There are few researches on the processing technology of honeycomb plate heat exchanger. In fact, the honeycomb plate processing method will have a significant effect on heat transfer efficiency. At present, a new type of honeycomb plate heat exchanger plate processing method has been proposed. First, the two pieces of steel plate in advance of spot welding, so that the two plates connected together. Second, the steel plate is sealed around by welding. Third, use of hydraulic bulging technology to make the steel plate deformation formation gap, the final formation of honeycomb-like heat transfer plate. Compared with the traditional stamping molding, hydraulic bulging has the advantages of high production efficiency, short manufacturing cycle, low labor intensity and lower labor cost. However, the use of hydraulic pressure-rise method, will lead to the welding point in the hydraulic pressure to withstand a sharp increase in load. In addition, in order to increase the heat transfer effect, the steel plate making the heat exchanger sheet becomes thinner, but too thin steel plate will bring great difficulty to the processing and manufacturing. Especially in welding, the thin steel plate is easy to burn through the welding failure. Thus, it is necessary to use the experiment to determine the reasonable value of weld strength and liquid pressure.

In this paper, the technology of manufacturing welded honeycomb plate heat exchanger by hydraulic bulging was studied. The influence of welding mode, weld shape and welding point arrangement on the mechanical strength of honeycomb plate was analyzed. The reasonable processing parameters of honeycomb plate heat exchanger were determined. The research results of the project can provide technical assistance for the application of honeycomb plate heat exchanger.

Figure 1. Structure diagram of honeycomb plate heat exchanger

Materials and methods

Processing methods of honeycomb plate heat exchanger

Honeycomb plate heat exchanger piece structure

The Honeycomb plate heat exchanger is designed to realize high efficiency refrigeration, the concrete structure is 2.4 m × 1.2 m, as showed in fig. 1. First of all, heat transfer plate by two pieces of thin steel plate for peripheral rolling welding and sealing edge treatment, the steel plate for welding. Then, after stamping, forming and other processing process made. The solder joint should be arranged according to some distribution rules. This type of honeycomb plate heat exchanger has a closed honeycomb-like flow path, formed a plate heat exchanger high pressure staggered circulation structure. These staggered circulation structures make the cold and hot fluid inside the plate heat exchanger to produce strong turbulence and achieve high heat transfer effect.

Honeycomb plate heat exchanger material

The material used for making honeycomb plate heat exchanger is 06Cr19Ni10. This is a Chinese steel grade. The corresponding U. S. steel grade is ASTM304. The 06Cr19Ni10 is a widely used chromium-nickel stainless-steel, with good corrosion resistance, heat resistance, low temperature strength and mechanical properties, with good processing performance and solderability, is widely used in the production of the requirements of a good comprehensive energy (corrosion resistance and molding) of equipment and parts, especially suitable for heat exchanger chip manufacturing. The main internal components are showen in tab. 1.

Table 1. Mechanical properties of 06Cr19Ni10 [16]

Chemical constituents					Mechanical properties				
C	Si	Cr	Mn	Ni	Yield strength [Mpa]	Tensile [Mpa]	Elongation [%]	Hardness [HB]	Young modulus [Mp]
≤0.08	≤1.00	18~20	≤2.00	8~11	205	520	40	187	1904020

Welding method of honeycomb plate heat exchanger

At present, laser deep penetration welding technology is widely used in honeycomb plate heat exchanger. It means the use of high power density laser irradiation on the steel plate surface, is the steel plate material evaporation form key-hole structure, key-hole and the molten metal around the hole wall with the leading beam forward speed move forward, molten metal filled with key-hole removed after leaving the void and then condensing, then forming weld. This method makes a very high-power density, small heat affected zone and deformation, and high mechanical strength of weld, which is suitable for honeycomb plate heat exchanger processing [17].

Welding mechanical strength tests

In the machining process or working process, once the honeycomb plate heat exchanger has welded structural fracture, it will modify the flow law of the medium fluid and affect the heat exchange effect. If the solder joint is damaged, the leakage of the dielectric fluid will lead to the failure of the whole heat exchanger sheet. Therefore, it is important to study the shape of weld to ensure that the mechanical strength of the weld seam between radiator plate meets the requirement.

Firstly, the welding sample is pretreated before welding. Two steel plates of 06Cr19Ni10 are cut 100 mm × 100 mm samples by line cutting machine. The surface of the sample is wiped off with acetone, then the oxide film on the specimen surface is removed by stainless-steel wire brush.

Second, two specimen plates are bonded together according to the predetermined weld geometry and welding process parameters by laser deep penetration welding method. The concrete operational method is:
– uses the spot welding method to connect two pieces of steel plate together,
– in according to the stipulation weld line shape to carry on the welding, causes these two plates tightly to engage, and
– in order to facilitate the testing of weld mechanical strength, the two steel plates behind each weld a steel tube, composed of a whole sample.

The material of the steel tube is also 06Cr19Ni10. The tube's external diameter is 25 mm, and its wall thickness is 1.5 mm. The steel tube welded specimen is installed on the universal tensile tester to record the tensile strength and the operation process as showed in fig. 2.

Figure 2. Experiment on mechanical strength of welding; (a) mechanical strength test diagram of weld, (b) weld sample diagram, and (c) weld test result diagram

In order to study the influence of different weld shape and length on the welding effect, two types of welding methods are adopted.

Method A: First, the two-steel plate spot welding, so that the initial bonding and determine the position, and then around the welding spot into a circle, forming a ring weld, as showed in fig. 3(a)

Method B: Similar to Method A, the difference is that the weld after the spot welding to form an incomplete circle, but to form an arc, the arc of the circumference angle of 300°, as showed in fig. 3(b).

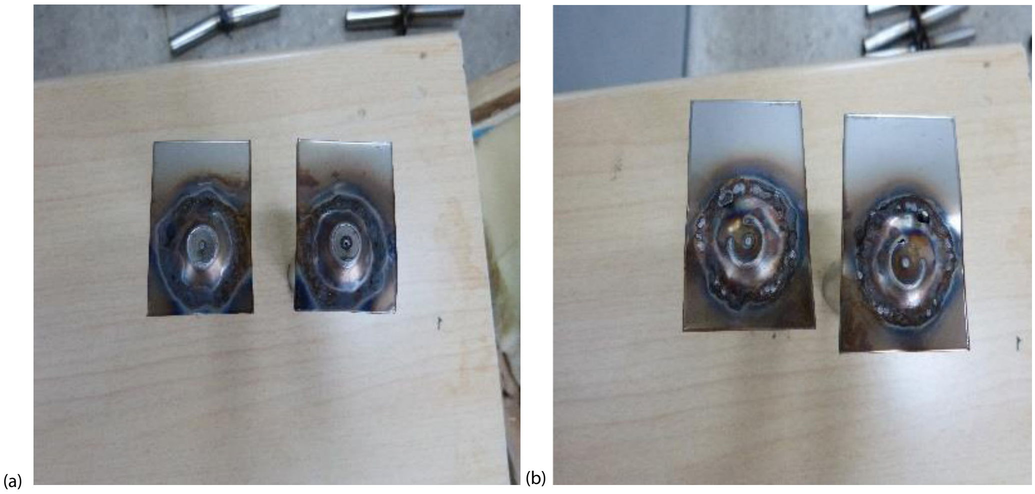

Figure 3. The geometric shape of weld; (a) Method A; b) Method B

Effect of different welding point arrangement on the pressure-rise performance of steel plate

This experiment is mainly used to detect the influence of different weld distribution on the welding strength during the hydraulic pressure-rise process. The specific method is that the number of solder dots is 15 points for the different welding points in the two solder joint distribution modes (equilateral and rectangles). The longitudinal columns of the rectangular and triangular solder joints are relative to each other, and the ability of diagonal compression with weak pressure is studied. The lay-out is shown in fig. 4.

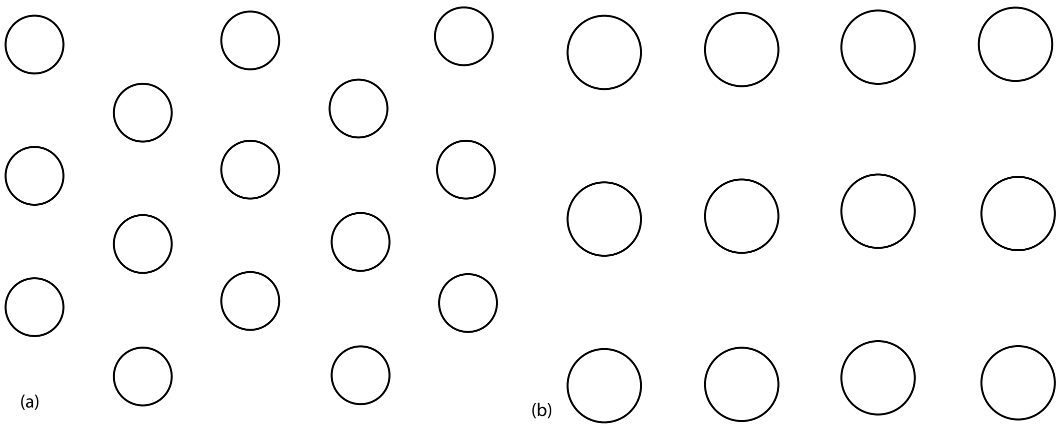

Figure 4. Arrangement of solder joints; (a) equilateral triangle arrangement, (b) rectangular arrangement

Temperature field control method of heat exchanger sheet

For the honeycomb plate heat exchanger, the temperature field control is very important. Especially when adopting liquid-liquid and no phase change heat exchange system, it is necessary to strictly control the flow, temperature and pressure of the outlet medium. According to the experience of engineering practice, the flow path of the cooling fluid in the heat exchanger, inlet temperature, external temperature and pressure of the heat exchanger are uncontrollable, because these variables are susceptible to interference. Therefore, in this paper, the cooling fluid-flow is taken as the control parameter, and the output temperature of the cooled medium is adjusted by using the control system, which is also the intelligent control scheme of heat exchanger.

For liquid-liquid heat exchange and no phase change system, requires the cold and hot fluid after the heat exchanger test pieces for heat transfer, heat flow through the heater to the required temperature, cooling fluid cooler to the required temperature, so as to achieve heat exchange cycle work.

At present, the traditional control method of heat exchange is fuzzy-PID control, and the response speed, stability, anti-interference ability and robustness of the system are further improved to meet the demand of different control in the industrial production. In order to verify whether the flow field after welding meets the cooling requirements, simple PID control is adopted in this paper.

Results

The experiment was carried out in August 2017, at the processing workshop of China Southwest Energy Technology Co., Ltd in Chongqing, China. The temperature was 25~27 °C in the test.

Mechanical strength analyses of weld seam

According to the contents described in the section, *Welding mechanical strenght tests* two samples were processed by 06Cr19Ni10 steel plate with thickness of 1.2 mm. The type of the CNC laser welding machine is LW-2160B. The variation range of welding power is from 1.6 kW to 3.0 kW, and the interval is 0.1 kW. The welding speed is stable at 2.5 m per minute. The circumferential diameter of the weld is 10 mm, and the tensile test is carried out on the DNS100 electronic universal testing machine. The results are shown in tab. 2.

Table 2. Mechanical strength of two kinds of weld with different shapes [kN]

No.	Welding power	A	B
1	1.6	42.56	12.24
2	1.7	44.78	20.17
3	1.8	47.62	22.26
4	1.9	46.54	27.31
5	2	48.79	20.89
6	2.1	52.70	32.04
7	2.2	43.26	34.64
8	2.3	26.27	38.26
9	2.4	22.95	18.27
10	2.5	28.76	19.52
11	2.6	16.89	14.23
12	2.7	15.64	12.26
13	2.8	15.02	10.15
14	2.9	14.11	8.86
15	3	12.46	7.23

Influence of spot weld lay-out on the limit pressure of hydraulic bulging

On the basis of experiment described in preceding section, the circular weld is determined, and the 15 points are distributed by two ways of rectangle and equilateral triangle, as showed in fig. 5. The variation range of welding power is from 1.8 kW to 2.2 kW, the distance between welding points is 30~70 mm, and the interval 10 mm is followed by water pressure punching test. When the weld is broken or the plate leaks, it is considered that the water pressure at this time is flat plate, which can withstand extreme pressure. The results of the experiment are shown in tab. 3.

Table 3. Limit pressure for different welding processes

Welding power [kW]	Distance [mm]	Arrangement	
		Equilateral triangle	Rectangular
1.8	30	16	14.7
1.8	40	11.5	11.2
1.8	50	9.2	8.1
1.8	60	3.6	3.1
1.8	70	1.8	1.6
2	30	17	15.6
2	40	12.8	11.7
2	50	6.4	6.1
2	60	3.1	3.2
2	70	1.9	1.7
2.2	30	19.0	17.4
2.2	40	15.3	12.3
2.2	50	10.2	8.9
2.2	60	6.4	5.7
2.2	70	3.2	2.1

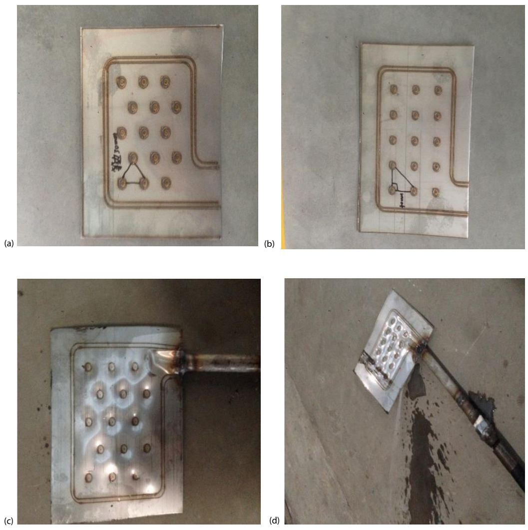

Figure 5. Influence of spot weld lay-out on the limit pressure of hydraulic bulging; (a) equilateral triangle arrangement, (b) rectangular arrangement, (c) test sample, and (d) test site photo

Parameter determination of heat exchange control system

The control system of the heat exchanger is shown in the fig. 6. When the temperature of the heat exchanger outlet medium changes constantly, the temperature transmitter signal will also change constantly. The system bias is obtained by comparing the input and given values. After sampling and conversion, the deviation signal is output after the controller is operated and amplified. After conversion, it is sent to the actuator to control the opening of the valve. The flow rate is adjusted to keep the outlet temperature of the heating medium stable at a given value or within the allowed range. Traditional PID control experience formula, determine the parameters of PID controller is: $K_p = 1200$, $K_i = 1020$, and $K_d = 360$.

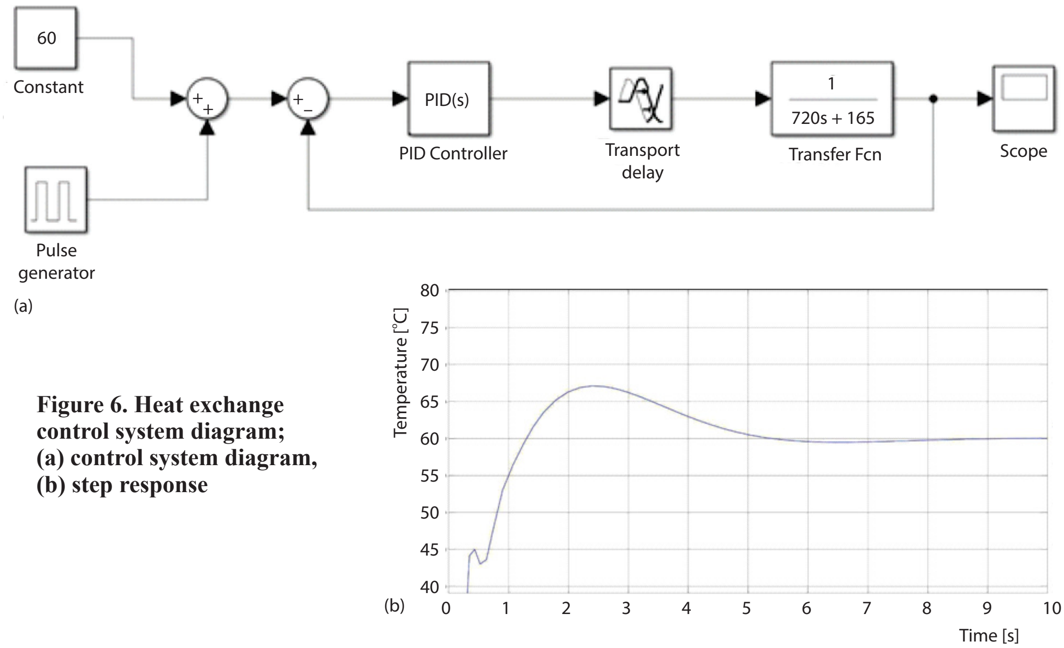

Figure 6. Heat exchange control system diagram; (a) control system diagram, (b) step response

Conclusions

These experimental results show that the weld shape has great influence on the bonding strength of the stainless-steel plate in the processing technology of the honeycomb plate heat exchanger. The effect of spot welding is to make the initial bonding and positioning of the two-thin plate. Therefore, for the welding, the strength of the circular weld is greater than that of the arc weld. Therefore, in the process of the honeycomb plate processing, the weld has a great strength. The length of the weld should be increased as much as possible. In the actual machining process, a spiral weld is adopted. As showed in the picture, the strength of the two kinds of welds is higher than that of the experimental ones.

For the steel plate with the specified thickness, the energy and energy of laser welding have the best solution. Too high or too low welding energy will affect the welding quality, and the high welding energy will result in the penetration of the weld. Therefore, it is not recommended to use high welding energy.

When the hydraulic bulging is applied, the position of the solder joint has a very significant effect on the pressure rising effect. The experiment proves that the triangle welding method is better than the right-angle welding.

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Nomenclature

K_i – integral coefficient
K_d – differential coefficient
K_p – proportional coefficient

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